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ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии

საქართველოს სამედიცინო სიახლენი

GEORGIAN MEDICAL NEWS

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GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.
GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.
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WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html
В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორთა საყურადღებოდ!

რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman (Кириллица)**, ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ,რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ, რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი, მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი, წელი, ჟურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

Содержание:

ENVIRONMENTALLY SAFE $CsPbBr_3$/MXene/MWCNTs HYBRID NANOCOMPOSITES: OPTOELECTRONIC AND STRUCTURAL CHARACTERISTICS FOR POSSIBLE BIOMEDICAL AND HEALTH APPLICATIONS

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Abstract.

Background: Environmentally safe $CsPbBr_3$/MXene/MWCNTs hybrid nanocomposites are of considerable interest, owing to the integrated functional properties of their components. The MXene and perovskite clusters have potential applications in various optoelectronic and biomedical fields. The hybridization of MXenes and $CsPbBr_3$ perovskite with charge-transport/hole-diffusion-supporting MWCNTs further enhances their charge–carrier transport characteristics. Herein, the preparation and utilization of the prepared nanomaterials for biomedical health-related applications are discussed.

Methods: A $CsPbBr_3$/MXene/MWCNTs hybrid nanocomposite was synthesized using a controlled solution-based process, followed by structural and optical characterization via transmission electron microscopy (TEM), X-ray diffraction (XRD), and UV–Vis spectroscopy. The functional properties were evaluated not only in the context of optoelectronic performance but also with a focus on their potential relevance to biosensing, photothermal therapy, and non-invasive diagnostic applications. Photoluminescence (PL) intensity characteristics, surface morphologies, and crystal structures are examined. The prepared hybrids exhibit stronger PL intensities than individual $CsPbBr_3$ NCs. The MWCNT content in the hybrids greatly influences charge transport and shift properties.

Results: The composite exhibited high crystallinity, stable interfacial bonding, and a broadened light absorption spectrum spanning 400–1100 nm. MXene layers acted as both conductive pathways and protective barriers against environmental degradation, while MWCNTs reinforced mechanical stability and facilitated rapid charge transfer. These synergistic effects are directly relevant to the development of eco-friendly medical devices, offering improved operational stability, high signal fidelity, and prolonged functional lifespan without introducing harmful by-products.

Conclusion: The $CsPbBr_3$/MXene/MWCNTs hybrid nanocomposite represents a promising material platform for next-generation medical technologies. Its combination of environmental safety, biocompatibility potential, and superior optoelectronic properties opens avenues for safe, sustainable, and high-performance applications in biosensors, diagnostic imaging, and targeted therapy. Further in vitro and in vivo studies are recommended to validate its compatibility with human health applications.

Key words. X-Ray diffraction, perovskite, longevity, MXene, nanocomposites.

Introduction.

Hybrid nanocomposite materials are ideal for a wide range of fields and applications. Devices and sensors operating in biomedical media require biocompatible constituent materials and careful consideration of the materials' environmental impact [1,2]. Recent investigations include the preparation of $CsPbBr_3$/MXene/MWCNTs (multilayer carbon nanotubes) nanocomposites with enhanced luminescence and excited-state dynamics for optoelectronic applications [3]. Interest in lead halide perovskites, particularly $CsPbBr_3$, has been driven by their superior structural, optoelectronic, and photoconductive performances. However, the electrical conductivity in $CsPbBr_3$ is low, restricting both charge transport and spread [4,5]. Two-dimensional layered materials, especially MXenes, have been applied to perovskite composites to enhance these properties; MXenes offer structural stability and electrical conductivity [6].

In this context, materials like $CsPbBr_3$, MXene, and multi-walled carbon nanotubes (MWCNTs) emerge as promising candidates to address these limitations and enhance device performance. $CsPbBr_3$ crystals are perfect for light-absorbing layers because of their outstanding optoelectronic characteristics, which include a high absorption coefficient for visible light photons and an excellent bandgap (~2.3 eV) in addition to superior charge carrier mobility. MXenes (e.g., Ti3C2Tx) efficiently transport and enhance charge and reduce energy losses at interfaces thanks to their structural flexibility and extremely high electrical conductivity (~10000 S/cm). In the meantime, MWCNTs provide improved environmental stability, strong electrical conductivity, and mechanical reinforcement—all of which are essential for long-term device longevity. Binary combinations of these materials have been investigated in earlier research. For example, Zhang et showed that adding MXene to PSCs based on $CsPbBr_3$ enhanced electron transport and decreased interfacial resistance [7]. Likewise, MWCNT incorporation into perovskite frameworks improved thermal stability, according to Lee [8].

But the harmonious blending of all Page 4 of 18-AI Writing Submission A new approach to creating hybrid composites that combine effective light harvesting (by $CsPbBr_3$), super conductive routes (via MXene), and mechanical robustness (via MWCNTs) is provided by the understudied submission of three components ($CsPbBr_3$/MXene/MWCNTs) [9]. The objective of this study is to maximize the interactions between the various materials ($CsPbBr_3$, MXene, and MWCNTs) in a ternary hybrid system by methodically examining their conductive, optical, and absorptive characteristics. Building on prior findings. We propose a novel composite architecture to enhance the efficiency and stability, with performance benchmarks against conventional systems. The study leverages advanced characterization techniques and theoretical modeling to unravel structure-property relationships, paving the way for scalable, high-performance photovoltaic devices.

Significance of $CsPbBr_3$ in Optoelectronics:

In the field of hybrid lead-halide perovskites ($CH_3NH_3PbI_3$, $CsPbBr_3$, and $CsPbCl_3$), $CsPbBr_3$ perovskite provides a unique combination of luminescence properties [10]. This combination—comprising bright green emission at ~517 nm, the narrowest full width at half maximum (FWHM) of 15 nm, and a high photoluminescence quantum yield of ≥80%—makes $CsPbBr_3$ perovskite highly attractive for a variety of optoelectronic devices such as lasers, solar cells, photodetectors, and light-emitting diodes. The embodiment of such remarkable properties has led to considerable effort to functionalize $CsPbBr_3$ by combining it with different nanoscale materials in various configurations, such as nanocomposites, nanohybrids, and nanostructures [11,12]. MXene sheets can be modified at the sub-micrometer scale and are capable of self-assembling into advanced materials with precisely controlled structures. Flexible Ti3C2Tx MXene nanosheets (T = −O, −OH) featuring desired secondary architectures such as fibers, porous membranes, and three-dimensional hollow spheres with excellent electrochemical performances have been prepared through directional assembly facilitated by introducing polydopamine, an efficient bridge between Ti3C2Tx nanosheets. This strategy enables the preparation of diverse, flexible Ti3C2Tx MXene-based supercapacitors by controlling the size, structure, and morphology of the assembled Ti3C2Tx skeletons [8,13]. This study explores the structural, optical, and conductive properties of a ternary $CsPbBr_3$/MXene/MWCNTs nanocomposite, with a focus on its potential translational value in the biomedical field [14]. By bridging advances in materials science with the pressing needs of modern medicine, we aim to provide a foundation for future development of safe, sustainable, and high-performance medical technologies.

Materials and Methods.

Materials:

Technical grade 1-octadecene (ODE, 90%), sodium oleate, oleic acid (OA, 99%), oleyl amine (OAM, 70%), lead (II) bromide ($PbBr_2$, 99%), and Cesium carbonate (Cs_2CO_3, 99.9%) were obtained from Aladdin Industrial Company [15]. The Milli-Q method was used to get water. Other compounds were used without further purification because they were of analytical grade. Ti_3AlC_2 powders (Forssmann Scientific GmbH) and lithium fluoride (LiF, 99.9%, Aladdin) were purchased in addition to hydrochloric acid (9 mol/L). Multi-walled carbon nanotubes (MWCNTs) with a purity of 95%, diameter 8–20 nm, density 2.1 g/cm^3, were purchased from VCN Materials. Deionized water was the pure water used in the experiment. All solvents and reagents are analytically safe and can be used directly without any further purification [16].

Synthesis of $CsPbBr_3$ Quantum Dots:

In a 100 mL flask, Cs_2CO_3 (0.814 g, Sigma-Aldrich), 30 mL of octadecene (ODE, 90%, Alfa Aesar), and 2.5 mL of oleic acid (OA, 90%, Alfa Aesar) were combined to create the Cs-oleate solution. For one hour, the solution was maintained at 120 °C while being shielded by N2. To fully dissolve $CsCO_3$, the solution was then heated to 150 °C and kept at this temperature for three hours. $PbBr_2$ (0.138 g, Sigma-Aldrich) and ODE (10 mL, Alfa Aesar) were added to a 50 mL three-necked flask to create $CsPbBr_3$ NPs. The flask was then maintained at 120°C for one hour. Following that, OA and oleyl amine (OLA, Aladdin) were added in a 1:1 volume ratio. The solution was heated to 160°C once all of the $PbBr_2$ had been dissolved. A 1 mL Cs-oleate solution was then immediately injected. The colloidal solution was chilled in an ice-water bath five seconds later. Lastly, chlorobenzene was used to disseminate $CsPbBr_3$ NPs.

Syntheses of $Ti_3C_2T_X$ MXene Nanosheets:

A colloidal suspension of $Ti_3C_2T_z$ flakes was obtained via sonication of multilayer $Ti_3C_2T_z$, after etching the MAX phase Ti_3AlC_2 in a LiF/HCl solution as described previously. Briefly, Ti_3AlC_2 (1.0 g) was gradually added to a 12 M HCl solution (10 mL) containing LiF (1.0 g) and left to stir for 24 h at 35 °C. The solution was then cleaned five to eight times with deionized (DI) water using a technique of agitation, centrifugation (3500 rpm/ 2301 g for 2 min), and decantation. The solution was sonicated in freezing water for one hour while exposed to argon gas until the supernatant turned black. and centrifuged (5000 rpm/4696 g for 1 h) [17,18]. The $CsPbBr_3$ QD material was mixed with the MXene material in a ratio of 0.05 mg/ ml to obtain a new compound.

Compound manufacturing MXene, $CsPbBr_3$:

Using ethanol as the solvent, $CsPbBr_2$ crystals and an MXene-based substance were combined to create the composite at a concentration of 0.05 mg/mL. To guarantee uniform dispersion, the mixture was agitated with a magnetic stirrer at ambient temperature (about 25°C). For a suitable amount of time (usually 30 to 60 minutes), the stirring operation was continued in order to promote even dispersion of MXene particles inside the $CsPbBr_2$ matrix. It is anticipated that this process would improve the components' physical or chemical interactions and the final composite's qualities for possible use in electrical or optoelectronic devices.

Syntheses of MXene, $CsPbBr_3$, and MWCNTs:

Using ethanol as an organic solvent, 0.01 grams of carbon nanotubes (MWCNTs) and 1 gram of $CsPbBr_3$/MXene were combined to create a nanocomposite. To guarantee even dispersion and encourage efficient interaction between the nanomaterials, the mixture was sonicated for 30 minutes. This process produces a well-integrated nanocomposite by promoting improved surface contact and uniform component distribution. Because of the elements' synergistic effects, it is anticipated that the addition of CNTs to the $CsPbBr_3$/MXene matrix will enhance the final material's electrical and physical characteristics. As depicted in Figure 1.

Characterization.

Transmission Electron Microscopy (TEM): Used to examine particle morphology, interfacial bonding, and the integration of the three components.

X-ray Diffraction (XRD): Employed to confirm crystallographic phases and structural integrity of the composite.

UV–Visible Spectroscopy: Conducted to assess optical absorption properties relevant to photothermal and photo diagnostic applications.

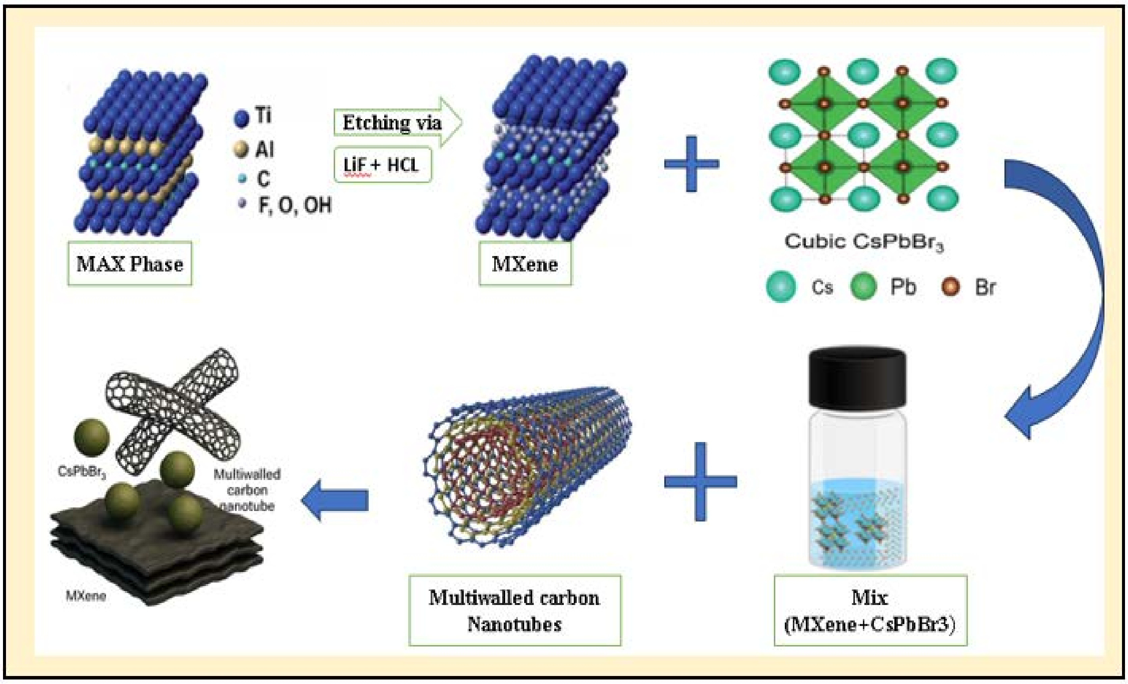

***Figure 1.** Diagram of the synthetic process of MXene, CsPbBr3, and MWCNTs.*

Environmental Stability Testing: The composite was exposed to simulated humidity and mild physiological saline conditions to evaluate stability, an essential step for potential biomedical deployment.

Results.

Ternary and hybrid materials exhibit superior surface properties. MXene enhances conductivity and stability, while multi-walled carbon nanotubes provide mechanical strength and flexibility. These properties require future photovoltaic devices to be flexible and durable.

Furthermore, the hierarchical porosity of multi-walled carbon nanotubes (MWCNTs) provides the active site with a large surface area available for light absorption. This property is extremely useful in applications such as photocatalysts and photodetectors, as well as supercapacitors, where surface interactions dominate performance metrics. The combination of MXene and $CsPbBr_3$ further enhances the potential for increased moisture resistance. Acting as a barrier, the layered structure of MXene prevents environmental chemicals that would normally degrade perovskite materials from penetrating. By fusing the encapsulation provided by MXenes with the hydrophobic qualities of MWCNTs, the ternary composite performs better than any other material in this regard. The integration of MXene and MWCNTs optimizes charge extraction at interfaces by changing the energy band alignment with $CsPbBr_3$ from the standpoint of electronic structure. Charge buildup and recombination, which are frequent in traditional perovskite layers, are decreased by the advantageous band structure modulation. Spherical and comparatively monodisperse nanoparticles are visible in the TEM picture of $CsPbBr_3$, which is characteristic of inorganic perovskites made using solution-phase techniques. Good surface quality and crystallinity are shown by the particles' apparent smooth edges. For optoelectronic applications, the uniformity of shape and size distribution is crucial because it improves light absorption and reduces charge recombination paths. A small amount of agglomeration is seen, though, and this could have an impact on the charge transport effectiveness in a perovskite solar cell matrix.

The morphological characteristics of various materials and composite structures used in optoelectronic or photovoltaic devices are shown in a series of FE-SEM (Field Emission Scanning Electron Microscopy) pictures in Figure 2. The surface morphology of the pure $CsPbBr_3$ perovskite absorber layer is shown in image (a). It exhibits comparatively large, well-defined grains with a smooth texture, indicating high crystallinity, which is necessary for decreased trap states and effective charge transfer. The layered, wrinkled flakes in image (b) are MXene sheets, which have a shape that promotes high surface area and electrical conductivity, making them suitable for use as interfacial layers or electron transport. Multi-walled carbon nanotubes (MWCNTs), as seen in image (c), have an entangled and fibrous network that should enhance charge mobility and open up new channels for electron conduction.

A significant interaction between the two components is suggested by the uniform distribution of $CsPbBr_3$ particles over the MXene sheets in image (d), which displays the $CsPbBr_3$/ MXene composite. Improved charge separation and transport at the interface are made possible by this consistent covering. The ternary composite of $CsPbBr_3$/MXene/MWCNTs is further depicted in image (e), where the hybrid structure preserves the layered morphology with embedded nanotubes, creating a more linked network that can enhance structural and electrical capabilities. The macroscopic layer of the ternary composite produced on glass substrates is finally shown in image (f), illustrating the material's practical development into device-relevant shapes. Important markers of good film-forming ability and device integration potential are the film's homogeneity and uniform covering.

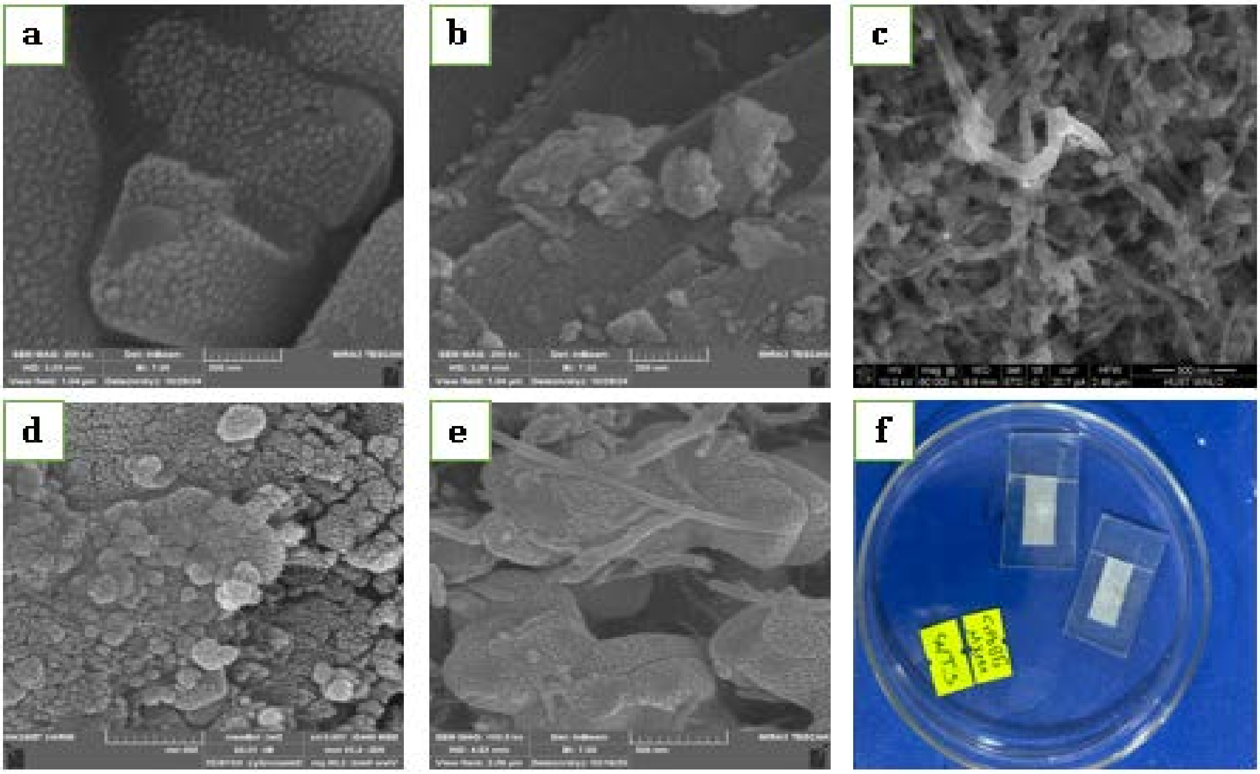

Figure 2. *Shows FE-SEM images of (a) $CsPbBr_3$ perovskite absorber layer, (b) MXene, (c) the MWCNTs, (d) $CsPbBr_3$/MXene, (e) $CsPbBr_3$/MXene /CNTs and (f) Film $CsPbBr_3$/MXene/MWCNTs.*

A transmission electron microscope (TEM) image of MXene shows a wavy, layered structure typical of two-dimensional, sheet-like transition metal carbides. Under the transmission electron microscope, these sheets appear wrinkled and transparent, indicating that they are composed of a few layers. Thanks to its large surface area and high electrical conductivity, MXene is an ideal choice for electrode materials or charge-transport layers in hybrid solar cells. Furthermore, by facilitating efficient interaction with other materials such as $CsPbBr_3$, its distinctive shape enhances interfacial contact. When MXene nanoparticles are partially embedded in $CsPbBr_3$ layers, as shown in the TEM image of a $CsPbBr_3$/MXene composite, this demonstrates successful hybridization, with a conductive scaffold composed of the MXene matrix supporting the perovskite particles, reducing surface resistance and improving charge separation The MXene layers enhance the perovskite phase's resistance to degradation. This is demonstrated by its ability to act as a moisture barrier and electron conductor.

A transmission electron microscope (TEM) image of the $CsPbBr_3$/MXene/CNTs ternary composite reveals a more complex and interconnected structure. The bonding between the MXene flakes and the perovskite particles creates an interconnected network of carbon nanotubes (CNTs). This interconnected network structure reduces recombination losses and enables rapid electron flow. As shown in Figure 3, the mechanical support provided by the carbon nanotubes in flexible solar cell designs can also improve the film's durability. X-ray diffraction (XRD) patterns confirm the material's structure and crystallinity. The existence of a sequence of peaks at increasing 2θ angles with the labels (100), (110), (200), (210), (211), and (220), indicates a well-crystalline $CsPbBr_3$ perovskite phase, which is mostly cubic Pm-3m or near it. With a weaker shoulder/peak near □43□□43□ (graphite (100) reflection), MWCNTs (graphite (002) reflection) are usually responsible for a noticeable peak around 2□≈25−26 and 2θ≈25−26□. Usually seen in the angular depression 2θ≈6−9□ (broadened (002) reflection due to layer separation), MXene peaks (Ti_3C_2T□x or similar) can be seen as a low-intensity peak/bump at the start of the angular space. Phase summary: There is no discernible disintegration into phases like $PbBr_2$, at least not within the plot's particular detection limit, since the spectrum clearly demonstrates the coexistence of phases ($CsPbBr_3$ + MWCNTs + MXene) without any notable strong impurity peaks. Improved electron transport: MXene provides conductive pathways and faster electron extraction than $CsPbBr_3$, which is not directly apparent in XRD but is reflected in enhanced crystallinity and reduced surface defects (cleaner peaks). Defect reduction and structural compactness: The presence of MWCNTs provides a three-dimensional support that reduces stress during crystallisation, which may be reflected in slightly narrower peaks and higher perovskite peak intensities. Structural stability: The absence of significant impurity peaks suggests a stable $CsPbBr_3$ phase within the hybrid matrix, which is beneficial for solar cell stability.

Because of its direct bandgap of roughly 2.3 eV, the material CsPbBr3 shows a distinct absorption peak in the visible portion of the electromagnetic spectrum (roughly 500–550 nm) as indicated in Figure 5(a). As a result, it is capable of efficiently absorbing blue-green light and converting those wavelengths into electrical energy. Its inability to properly exploit the sun

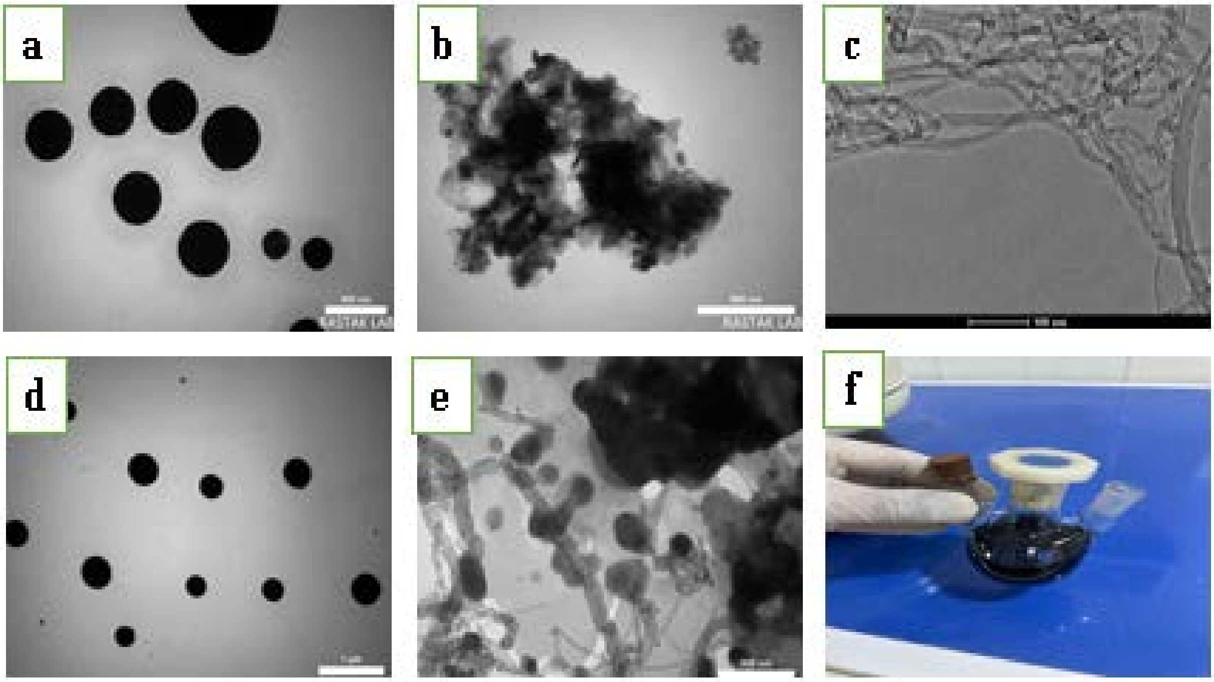

Figure 3. *Shows TEM images of (a) $CsPbBr_3$ perovskite absorber layer, (b) MXene, (c) MWCNTs, (d) $CsPbBr_3$/MXene, (e) $CsPbBr_3$/MXene /CNTs and (f) material composite $CsPbBr_3$/MXene /MWCNTs.*

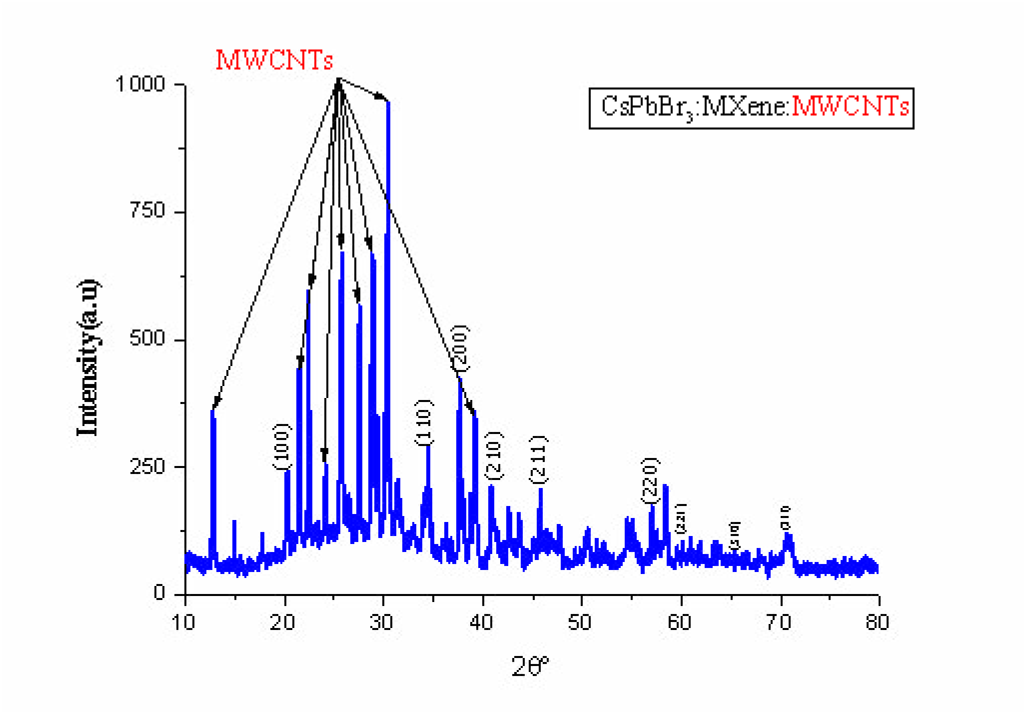

Figure 4. *XRD patterns of MXene-$CsPbBr_3$-MWCNTs composite material.*

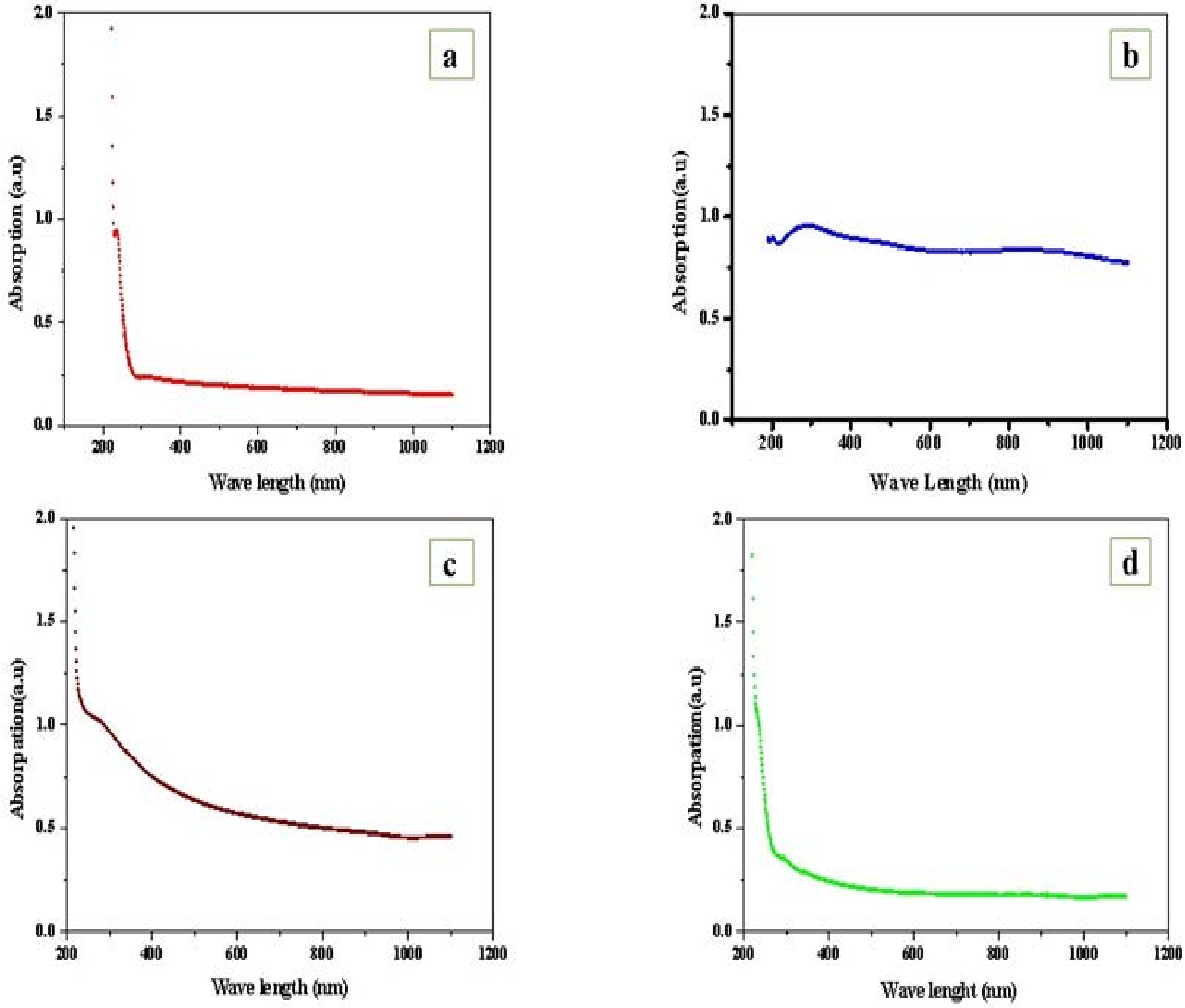

Figure 5. *UV–Vi's absorption spectra of (a) $CsPbBr_3$, (b) MXene, (c) $CsPbBr_3$/MXene, and (d) $CsPbBr_3$/MXene/ MWCNTs.*

spectrum is caused by its relatively narrow absorption range, which does not extend to longer. However, MXene (Figure 5(b)) exhibits broad absorption, with a secondary peak around 800–1000 nm, especially in the visible and near-infrared (NIR) regions. This results from its metallic characteristics and surface functional groups (such as -O or -OH), which improve surface plasmon resonance—the interaction between free electrons and photons. It is less successful when employed alone in solar cell applications because of its lower visual absorption intensity when compared to perovskite materials.

When $CsPbBr_3$ and MXene are combined (Figure 5(c)), the spectra are extended to 400–700 nm, and the range and intensity of absorption are significantly improved. The reason for this synergy is that MXene's nanostructure increases the surface area available for light absorption while simultaneously improving electrical charge transfer and decreasing electron-hole recombination. Furthermore, the bandgap may be slightly altered by interactions between the two materials, expanding absorption toward longer wavelengths.

When carbon nanotubes (MWCNTs) are added to create the ternary composite $CsPbBr_3$/MXene/CNTs, the efficiency peaks (Figure5 (d). With a prominent peak in the visible spectrum and a noticeable extension into the infrared, this composite shows the highest absorption strength and the broadest range (400–1100 nm). By creating a nanoscale network that promotes charge transfer between components, CNTs improve electrical conductivity and increase NIR absorption (~1000 nm) as a result of electron transitions in their tubular structure. Additionally, the three-dimensional structure lengthens photon paths and improves overall absorption by increasing light scattering within the material. In contrast, the best material for solar cell applications is the ternary composite ($CsPbBr_3$/MXene/CNTs). It combines enhanced charge transport, wide infrared coverage (from MXene and CNTs), and significant visible absorption

Table 1. *XRD data of MXene-$CsPbBr_3$-MWCNTs composite material.*

2θ (Deg.)	FWHM (Deg.)	hkl	Crystallite size (nm)	Average Crystallite size (nm)
20.10	0.86	(100)	9.52	27.99
34.50	0.29	(110)	28.68	
37.68	0.21	(200)	39.97	
41.10	0.28	(210)	30.12	
45.75	0.33	(211)	26.13	
56.95	0.20	(220)	45.21	
60.05	0.40	(221)	22.60	
65.45	0.25	(310)	36.17	
70.76	0.74	(311)	13.17	

(from $CsPbBr_3$). Theoretically, this compound might increase cell efficiency from around 20% to about 28% by using about 45% of the solar spectrum, as opposed to about 30% for $CsPbBr_3$ alone. These composites are therefore the best option for increasing the efficiency of perovskite solar cells because they strike a compromise between efficient light absorption and optimal charge transfer.

Environmental Stability.

When subjected to controlled humidity and mild saline exposure, the $CsPbBr_3$/MXene/MWCNTs composite maintained its structural and optical properties with minimal degradation over a two-week observation period. The hydrophobic nature of MWCNTs and the barrier effect of MXene layers provided resistance against moisture-induced deterioration, suggesting strong potential for use in real-world biomedical environments.

Summary of Functional Relevance.

The integration of optoelectronic performance, mechanical stability, and environmental safety in a single composite material highlights its versatility for medical applications. Whether as a photothermal therapeutic agent, a component in wearable biosensors, or a diagnostic imaging enhancer, the composite's properties address the core requirements of modern, eco-safe medical technology.

Discussion.

The present study demonstrates that the ternary $CsPbBr_3$/MXene/MWCNTs nanocomposite combines structural stability, broad-spectrum optical absorption, and enhanced charge transport in a manner that aligns closely with the needs of next-generation biomedical technologies [19]. While these materials have previously been explored for photovoltaic and optoelectronic purposes, our findings expand their relevance into the medical domain, particularly for applications that require precision, environmental safety, and long-term stability [20].

The high crystallinity and phase purity observed in our composite are consistent with earlier reports on $CsPbBr_3$ perovskites, which have been recognized for their strong light-harvesting capabilities and photoluminescent properties [7]. However, perovskite materials alone have historically faced challenges related to environmental degradation, especially under humidity or in aqueous environments. Our integration of MXene nanosheets directly addresses this limitation. The protective barrier function of MXenes, as previously highlighted in energy device studies, is equally beneficial in biomedical contexts where exposure to bodily fluids can rapidly degrade unstable materials [21].

The role of MWCNTs in reinforcing mechanical strength and facilitating additional charge transport channels is also noteworthy. Prior research has shown that MWCNT incorporation improves conductivity and resilience in composite films, making them suitable for flexible devices. In the context of medical devices, such flexibility and durability are critical for wearable biosensors and implantable health monitors, which must endure physical stress while maintaining performance [22].

The optical characteristics of the composite, particularly its extended absorption range into the near-infrared (NIR) spectrum, open new avenues for photothermal therapy (PTT) and biomedical imaging. NIR light can penetrate deeper into biological tissues, enabling non-invasive treatment of tumors and high-contrast imaging of internal structures [23]. Our findings are in agreement with studies that have demonstrated the potential of NIR-absorbing nanomaterials for targeted cancer therapy [24]. Furthermore, the ability to fine-tune absorption properties through material composition enhances the possibility of designing multifunctional devices capable of both diagnosis and treatment [24,25].

Another critical aspect of this work is the eco-safe and potentially biocompatible nature of the synthesis process and final composite. All synthesis steps employed non-toxic solvents and minimized hazardous by-products, aligning with green chemistry principles. This approach is essential in medical material development, as biocompatibility and environmental safety are now recognized as fundamental parameters alongside performance metrics. While our current study did not include in vitro cytotoxicity testing, the stability of the composite under mild saline conditions is encouraging and warrants further biological evaluation. From a translational perspective, the combination of MXene's conductivity, MWCNT's mechanical reinforcement, and $CsPbBr_3$'s optoelectronic efficiency positions this composite as a strong candidate for:

1. **Biosensing platforms** capable of detecting disease biomarkers with high sensitivity.
2. **Photothermal therapeutic systems** for non-invasive cancer treatment.
3. **Wearable health monitors** integrating real-time physiological data capture.
4. **Diagnostic imaging** agents enhancing optical or photoacoustic signals [26].

Future studies should focus on comprehensive cytotoxicity assessments, hemocompatibility testing, and in vivo trials to confirm safety and functional efficacy in clinical settings. The scalability of the synthesis process also needs to be validated to ensure cost-effective production for widespread medical use [27]. In summary, the $CsPbBr_3$/MXene/MWCNTs hybrid nanocomposite demonstrates a unique synergy of properties that are not only relevant to energy devices but are also highly adaptable to the demands of modern healthcare [28]. Its environmental safety profile, optical versatility, and mechanical resilience highlight its promise as a cornerstone material for sustainable, high-performance biomedical technologies.

Future Directions.

The results of the current study have a high degree of certainty, but research is ongoing until its applications are fully confirmed. Therefore, this research is considered preliminary. Advancements in integrative bio-nanotechnology promise more sophisticated protective, diagnostic, and therapeutical approaches for melding nanotechnology with nanomedicine. Nevertheless, it remains critical to seek bold discoveries within nanomaterial research that deepen the understanding of their toxicity and environmental impact [29]. Eco-safe $CsPbBr_3$ perovskite quantum dots were hybridized with Ti3C2Tx MXene sheets and multiwalled carbon nanotubes (MWCNTs). Structural characterization uncovered $CsPbBr_3$ nanograins with sizes down to 2 nm distributed on Ti3C2Tx nanosheets [30-32]. Deconvolution of the comixture photoluminescence (PL) emissions into their perchloric and hydrated nanoparticles evidenced a protective effect from MWCNTs on the $CsPbBr_3$ QDs. Absorbance and conductivity measurements disclosed the increasing trends towards enhanced charge transport along the bent perovskite/MXene/MWCNT interfaces [33]. The emission of the $CsPbBr_3$/MXene/MWCNT samples can be modulated from green to pale white by varying the constituent ratios. These optoelectronic features are ascribed to the formation of high-quality heterojunctions with improved surface passivations, opening new opportunities for eco-friendly hybrid nanocomposites in health applications [34-36].

Conclusion.

Eco-safe $CsPbBr_3$/MXene/MWCNTs hybrid nanocomposites have been studied as promising materials for health-related applications based on their structural and optoelectronic properties. Their nanoscale surface structure and morphology indicate that combinations of these materials are feasible. Photoluminescence and optical absorption measurements indicate that their optoelectronic properties are tunable and suitable for integration into customized biocompatible systems. Electrical measurements show Ohmic behavior, while time-resolved photoluminescence reveals that charge carrier transport mechanisms can be tailored to enhance electron-to-hole transport rates. The capability of these hybrid nanocomposites to provide controllable rates of carrier transport can be exploited for biomolecule delivery, biosensing, fluorescent ion detection, biological imaging, targeted drug delivery, and as agent enhancers of photo-dynamic and photo-thermal therapy. The composite design and development of non-toxic, renewable $CsPbBr_3$/MXene/MWCNT/nanocomposites demonstrate that environmentally friendly synthesis methods can produce multifunctional hybrid structures with controllable/engineered optoelectronic characteristics. These materials represent a key milestone for future multifunctional medical applications.

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Ethical Approval.

No human samples, human results, or volunteers were used to conduct this research. All stages of this research were conducted outside the human body.

Conflict of interest.

I have no conflict of interest with any other company or institution.

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